Physical Modelling in Geotechnics

Reproduce the coastal landslide induced tsunami using centrifuge model

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ABSTRACT: Tsunamis associated with coastal landslides can cause a catastrophic impact on coastal areas. To date, many landslides induced devastating tsunamis have been reported such as the 2009 Samoa earthquake and tsunami, the landslide-induced tsunami by the Great Japan earthquake in March 2011. More recent evidence is the tsunami resulting from the strong Sulawesi earthquake with a magnitude of 7.5 in September 2018. Many attempts, including the land-based field investigation and comparing the pre-and post-earthquake bathymetric, have found the numerous coastal landslides that possibly triggered the Palu tsunami. This event in Palu bay shows that tsunami caused by landslides need to be studied. The centrifuge model test is a realistic physical model to study the submarine landslide. Several researchers conducted centrifuge modelling for submarine landslides using beam-type and drum-type centrifuges. They observed the stability and the motion of submarine landslides. However, the phenomenon of earthquake-induced landslides causing tsunami was not fully studied in previous research. The authors attempt to investigate the landslide that triggered the very first tsunami wave. This study examined the coastal landslide of the Kashima River Sand no.5 which was collected near the river mouth in Choshi, Japan. Under the 50-G condition, the model represents a sloping ground of 10.5 m depth, 7.5 m wide and 18.5 m long which is difficult to achieve under the 1-G condition at a laboratory. By means of a centrifuge, we are now able to reproduce and measure tsunami triggered by an earthquake-induced landslide. A high-speed camera and pore water pressure transducers were used to measure the landslide motion and the water-level fluctuation.

Keywords: tsunami, coastal landslide, Palu bay, centrifuge.

1 INTRODUCTION

Landslides are one of the most dangerous natural hazards that can affect people and society. Landslide events are often secondary phenomena that are triggered by other disasters such as meteorological disasters, earthquakes, and volcanic eruptions. Earthquakes can cause landslides in both onshore and offshore areas. In recent years, submarine landslides have attracted attention. Submarine landslides can cause tsunamis which have a catastrophic impact on coastal areas. Studying submarine mass movements and their consequences have been started from 1952 with the work of Heezen and Ewing on the Grand Banks slide and tsunami (Locat and Lee, 2009). As of today, many catastrophic submarine landslide events that generating tsunami have been reported including the submarine landslide in Nice International airport in 1979 that caused the loss of human lives and important construction damages (Dan et. al.2007), the dramatic landslide-generated Papua New Guinea tsunami in 1998, which devastated three villages with the loss of over 2200 lives (Tappin et al. 2008) or the landslide-induced tsunami by the Great Japan earthquake on March 2011. A more recent example is the tsunami resulted by the 2018 Sulawesi earthquake with magnitude Mw 7.5. The huge earthquake and tsunami hit property and life with more than 2000 fatalities which surprised the researchers as it followed an earthquake with a strike-slip rupture mechanism unbelievable to generate catastrophic tsunamis (Omira et al. 2019). After the earthquake-induced submarine mass movement which was generated tsunami in Papua New Guinea, a renewed interest has grown in a topic now called tsunamigenic landslides (Bardet et al.2003). For hazard assessment, the maximum initial amplitude of landslide tsunami around the source region is an important parameter (Sabeti et al.,2021). There are three different methods to estimate the maximum initial amplitude: physical modelling, analytical calculations and numerical simulations. The centrifuge model test is a realistic physical model to study on the landslide tsunami. This study examined the coastal landslide of the Kashima River Sand no.5 which was collected near the river mouth in Choshi, Japan. The objectives of this research are to physically model tsunamis generated by a landslide which is caused by an earthquake and to determine maximum initial amplitude of landslide waves.

2 METHODOLOGY

2.1 Centrifuge modelling and scaling law

A series of centrifuge shaking table tests was carried out using the beam-type centrifuge apparatus at the Disaster Prevention Research Institute (DPRI); Kyoto University (Fig.1) to reproduce the landslide induced tsunami. The maximum capacity and effective radius are 24 G-ton and 2.5 m. The maximum acceleration and displacement are 10g and 2.5 mm.

The scaling laws for submarine landslide have been studied by several researchers (Gue, 2012; Takahashi et al., 2016, Yin et al., 2018). In this study, scaling laws were adapted from Takahashi et al., 2016 and presented in the table 1.

Table 1 Scaling laws.

Term	Prototype	Model
Density	1	1
Stress and pressure	1	1
Acceleration	1	N
Length	1	1/N
Velocity	1	1
Time-dynamic	1	1/N

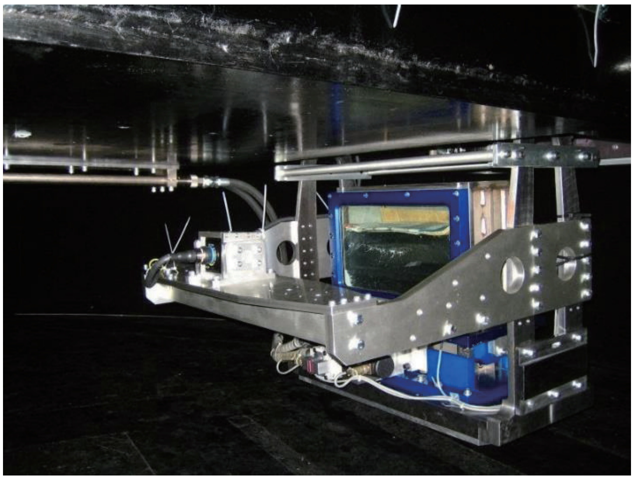

Fig. 1. The centrifuge at DPRI, Kyoto University (DPRI Geotechnical Centrifuge Center, 2010).

2.2 Model preparation and testing program

The Kashima River sand no.5 was used, the properties are summarized in table 2. From the particle size distribution (Fig.2), the brown sample had the particles with the mean diameter D_{50} = 0.43 mm, the coefficient of uniformity C_u = 2.63, the coefficient of curvature, C_c = 1.01. It is sand with fine < 5%. According to the Unified Soil Classification System in ASTM D2487, the soil was named Poorly graded sand.

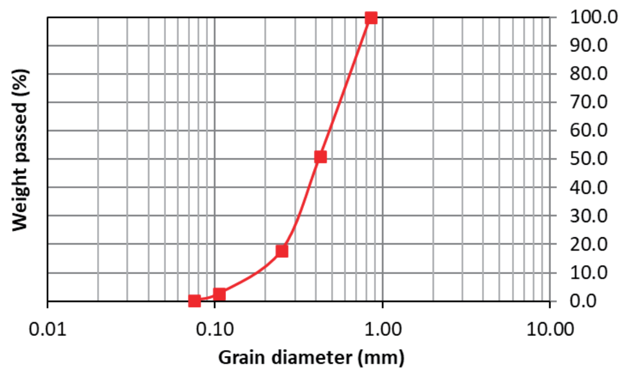

Fig. 2. Grain size distribution of Kashima River sand

Table 2 Properties of River Sand no.5.

Parameters	Value
Soil particle density, ρ_s	2.63 g/cm^3
Maximum void ratio, e_{max}	0.764
Minimum void ratio, e_{min}	0.561
Coefficient of uniformity, C_u	2.63
Coefficient of curvature, C_c	1.01
Mean particle size, D_{50}	0.430 mm

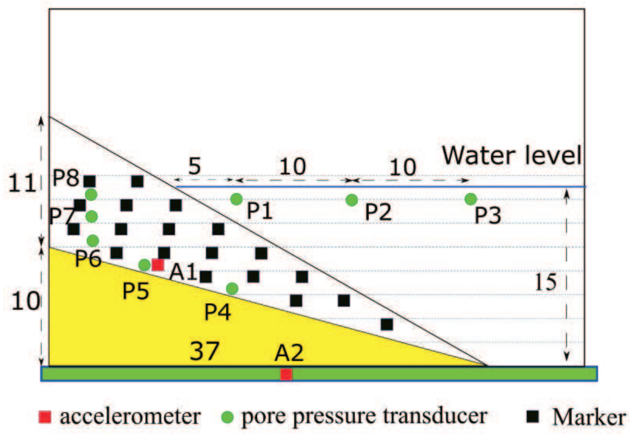

Fig. 3. Schematic view of model test (unit: cm)

Soil model slopes were prepared by mean of the stepwise moist-tamping procedure. In the soil slope, the water content of 10% and the relative density of 35% as loose sand. The soil model was put into a vacuum tank for at least 24h. During vacuuming, the de-air water was filled from the bottom of container until slope below water level. After saturation, the model was carefully transported into the shaking table of centrifuge and the water level was reduced to 15 cm. The centrifuge model test and instruments are shown in Fig.3. Two accelerometers, namely A1, A2 were used to measure the input motion. Five pore water pressure transducers, namely P4-P8 were installed in the slope to observe the excess pore water pressure during and after shaking, and three water pressure transducers (P1-P3) were used to measure tsunami waves.

Table 3. Test conditions.

Test ID	Relative density (%)	Slope angle (Degree)	Water level (cm)
Case 1	35	30	15
Case 2	35	30	18
Case 3	35	30	12

Three tests with water level of 12 cm, 15 cm and 18 cm were performed under a centrifugal acceleration of 50G to estimate the maximum initial amplitude of tsunamis. The test program was shown in Table 3. After the centrifugal acceleration reached 50g, the model ground was shaken with input motion from 2018 Palu earthquake (fig.4).

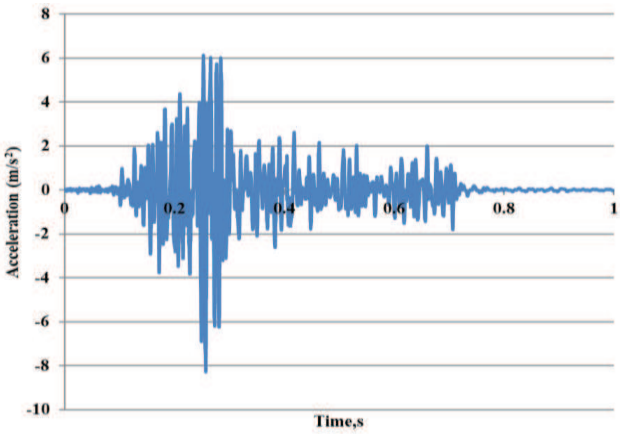

Fig. 4. Input motion during shaking.

3 TEST RESULTS AND DISCUSSION

To investigate the landslide induced tsunami, we need to separate tsunami causing by landslide and tsunami from input motion. Input motion has high frequency and it has affected to tsunami wave as blue line in Fig.5. Low-frequency filtering was used to remove high-frequency noise mainly associated with waves generated input motion. Fig.5 shows the measured data of case 1 at Pore water pressure transducer P1 (blue line) and low-pass filter data (red line).

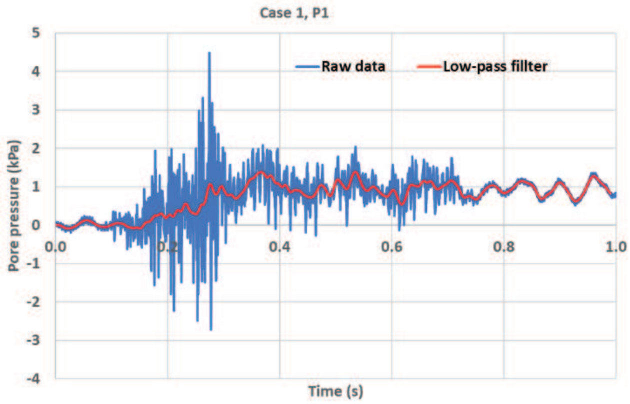

Fig.5 Low-pass filter pore water pressure record for case 1 at P1.

Fig.6 compares the tsunami waves at different water level of 12 cm, 15 cm and 18 cm. The figure shows that the larger wave crest amplitudes are observed when the water levels decrease from 18 cm to 12 cm. In this figure, the maximum initial waves crest amplitudes are about 12 cm, 5 cm, and 18 cm for case 1, case 2 and case 3, respectively.

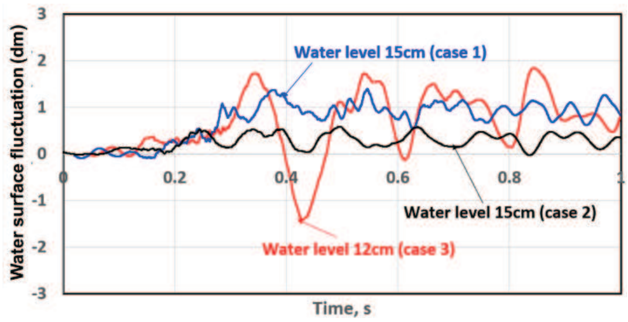

Fig.6 Water surface fluctuation at P1 with different water level

The primary conclusions of this study are as follows:

-Tsunamis generated by a landslide which is caused by an earthquake can be observed from the centrifuge test.

- Results of experiments show that the wave amplitude depends on the water level, when the water level increase, the maximum initial wave crest amplitude decrease. Increasing the water level led to an decrease of landslide volume and causing the decrease of wave amplitude.

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